Development of Pavement Maintenance Management System for Highway Network in Punjab, Haryana & Himachal Pradesh

A

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INTRODUCTION

India has a road network of over 5.8 million km as of November 2019, the second largest road network in the world. At 1.70 km of roads per square kilometer of land, the quantitative density of India's road network is higher than that of Japan (0.91) and the United States (0.989888) to, and far higher than that of China (0.46), Brazil (0.18) or Russia (0.08). Adjusted for its large population, India has approximately 4.63 km of roads per 1000 people. However, qualitatively India's roads are a mix of modern highways and narrow, unpaved roads, and are being improved. In spite of having such a vast network of road, the quality of road largely remains poor, so much so that more than half of the roads are still devoid of any kind of surface. It is high time that the maintenance and up grading of network is taken up without delay not only in the name of growth but for the economic factors as well.

Road transport is vital to India's economy. It enables the country's transportation sector to contribute 7.1 % towards India's GDP. Road transport has gained its importance over the years despite significant barriers and inefficiencies in inter-state freight and passenger movement compared to railways and air. The government of India considers road network as critical to the country's development, social integration and security needs of the country. India's road network carries over 65 percent of its freight and about 85 percent of passenger traffic. Indian road network is administered by various government authorities, given India's federal form of government. The total length of India's road network by type of road is given in table 1.

Table 1 Road Network in India

Road Classification	Authority responsible	Length (km)	Share of network length
Expressways	Ministry of Road Transport and Highways	1,585	0.03 %
National Highways	Ministry of Road Transport and Highways	1,01,011	1.80 %
State Highways	Public Works Department of State/Union Territory	176,166	3.14 %
MDR & ODR	Public Works Department of State/Union Territory	561,940	10.02 %
Rural Roads	Panchayats and PMGSY	3,935,337	70.21 %
Urban Roads	Local governments and municipalities	509,730	9.10 %
Project Roads	Various State/Union territory government departments and SAIL, NMDC and BRO	319,109	5.70 %
Total		**5,604,878**	**100%**

(Source-Basic Road Statistics of India 2015-16, MORT&H, GOI)

Pavement Management System (PMS)

Pavement management, in its broadest sense, encompasses all the activities involved in the planning, design, construction, maintenance, and rehabilitation of the pavement portion of a public works program as shown in figure 1. It is a set of tools or methods that assist decision-makers in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time. The function of a PMS is to improve the efficiency of decision-making, expand its scope, provide feedback on the consequences of decisions, facilitate the coordination of activities within the agency, and ensure the consistency of decisions made at different management levels within the same organization.

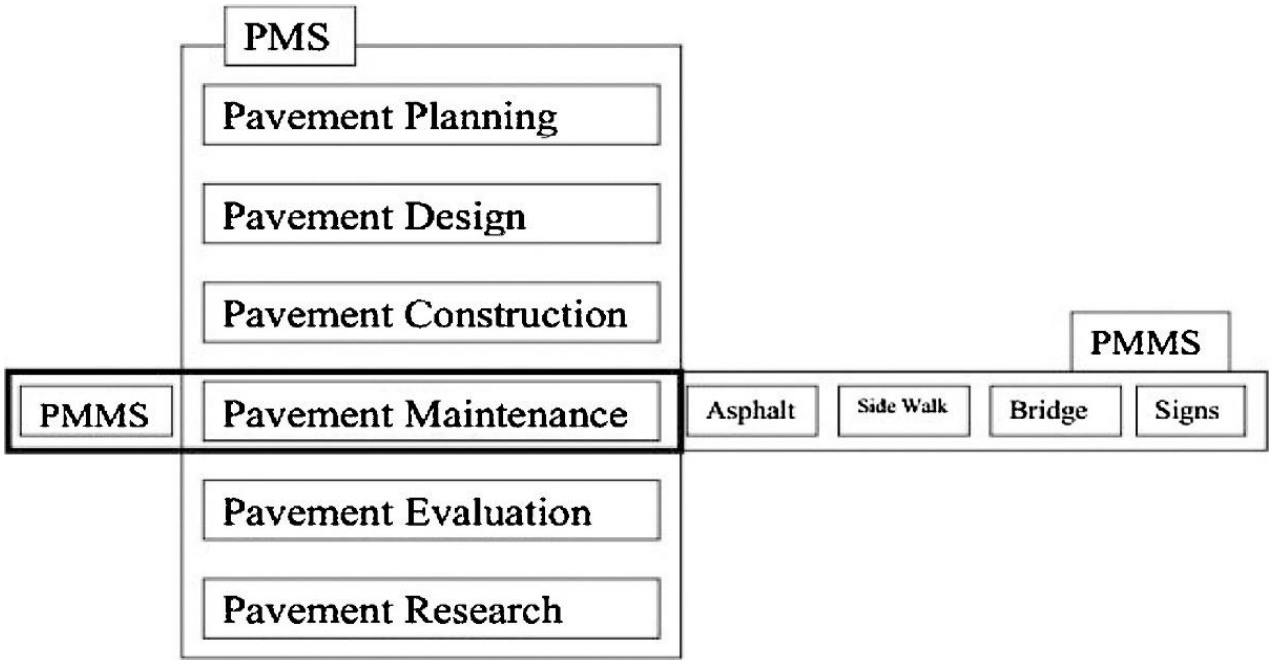

Fig. 1 Components of Pavement Management System

Pavement Maintenance Management System (PMMS)

The pavement maintenance management system (PMMS) is a systematic method for inspection and rating the pavement condition in a given area. The system also performs a cost effectiveness analysis of various maintenance and rehabilitation strategies. It generates a deterioration curve for each segment based on input then assigns the most cost-effective maintenance strategy based on condition, surface type and functional classification, and available budget.

Need of Maintenance Management

Research has shown that it is far less expensive to keep a road in good condition than it is to repair it once it has deteriorated. This is why pavement management systems place the priority on preventive maintenance of roads in good condition, rather than reconstructing roads in poor condition. Figure 2 shows Pavement deterioration curve illustrates the general concept of application of corrective pavement treatments as a function of pavement condition. This illustration contains three treatment zones as a function of pavement condition. The maintain, rehabilitate, and replace zone.

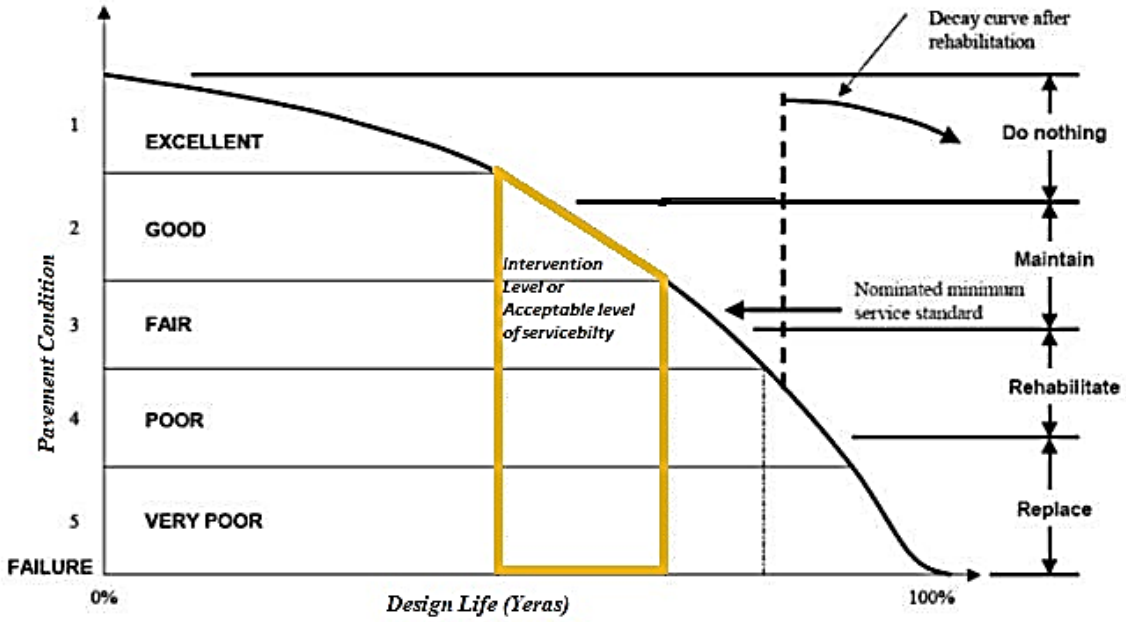

Fig. 2 Pavement Deterioration Curve

Advantages of Pavement Maintenance Management System (PMMS)

- More accurate and accessible information on the pavement network.
- Quantify the assessment of the condition of the pavement network.
- Ability to track the performance of specific treatment strategies.
- Identify needs to plan future activities and expense budgets.
- Support requests to state legislatures for additional funding for pavement maintenance and rehabilitation activities.
- Justify and support decisions as to project prioritization when dealing with local politicians or the public.

- Improve credibility when dealing with top management within the transportation agency.
- Provide a basis for allocating funds among different districts or agencies.
- Help select the best rehabilitation measures or strategies for different pavement management sections.

Tools of Pavement Management System (PMS)

There are different types of PMMS are practiced in highway maintenance and development like Global Road Technology Road Maintenance Software (GRTRMS) Program, Highway Development & Maintenance (HDM), Gestione Manutenzione Stradale (GeMaStra), PAVER, Pavement Analyst, dTIMS.

GeMaStra (Gestione Manutenzione Stradale) is a web-based application specifically designed for managing road maintenance. It is a concrete response to the requirements of administrations which must survey, analyses and manage the maintenance of their own roads. The incident and maintenance lists can be 'filtered' and ordered according to various criteria (date, road, type). Multi-field searches will also be possible in order to maximize ease of data access.

PAVER is the Pavement Maintenance Management System, originally was developed in the late 1970s to help the Department of Defense (DOD) manage M&R for its vast inventory of pavements. It uses inspection data and a pavement condition index (PCI) rating from zero (failed) to 100 (excellent) for consistently describing a pavement's condition and for predicting its M&R needs many years into the future. It provides pavement management capabilities to:

- Develop and organize the pavement inventory
- Assess the current condition of pavements
- Develop models to predict future conditions
- Report on past and future pavement performance
- Develop scenarios for M&R based on budget or condition requirements
- Plan projects

GRTRMS (Global Road Technology Road Maintenance Software) is a real-time data management system that collects a customized data set tailored to the individual needs of a client. It can help identify logistical or spending inefficiencies, and provides an immense amount of data useful at the strategic decision making level regarding infrastructure creation, budgeting, and maintenance costs.

Pavement Analyst is an advanced pavement management system (PMS) known internally at Caltrans as PaveM. PaveM utilizes pavement history, current pavement condition, current programmed projects, traffic, and climate data to predict future pavement conditions. It recommends pavement repairs needs using optimized strategies within funding constraints. The PaveM system is a complete Caltrans pavement network analysis tool. It uses “State of the Art” technology tools and stores High Definition photo imagery to collect the annual pavement condition survey to analyze every mile of pavement. PaveM answers questions such as, "Where should projects be built to achieve best pavement performance levels?" or "when should pavement preservation treatments be focused on priority routes to protect existing pavement investments?” As the annual pavement condition data is collected, better pavement performance prediction models will be developed for the many climate regions, traffic conditions and pavement types in California.

dTIMS (Deighton's Total Infrastructure Asset Management System) is a software product developed by Deighton Associates Limited which offers a set of tools for implementing a custom database and a custom analysis model. The software allows the user to create and maintain an inventory integrating any and all types of data (roads, bridges, signs, etc.) in one place and relate them together using location referencing. In addition, the software enables the user to perform life cycle cost analysis (LCCA) on those assets, meaning it will forecast condition into the future and determine the best maintenance or rehabilitation action subject to budget constraints.

Highway Development Management (HDM) is a software package and associated documentation which will serve as the primary tool for the analysis, planning, management and appraisal of road maintenance, improvements and investment decisions. In 1998, The World Road Association (PIARC) was entrusted by the stakeholders of the ISOHDM Project (International Study of Highway Development and Management) with the intellectual property rights of the software system known as HDM-4. Accordingly it has co-financed the development work culminating in HDM-4 Version 2.

The World Road Association Council, on the recommendation of the General Secretariat of PIARC, decided in 2004 to set up a service concession for the management, development, marketing, sales and support of HDM-4 Version 2 software.

HDM-4 is a computer software for Highway Development and Maintenance Management System. It is a decision making tool for checking the Engineering and Economic viability of

the investments in road projects. The World Bank for the global use has developed it. HDM-4 is used by government road administrations and agencies, development/funding banks, transportation consultants and education and transportation research institutions in over 110 countries.

There are four technical modules within HDM-4. The first three; Road deterioration (RD), maintenance and improvement effects (MIE) and Road user costs (RUC) are similar in scope to the equivalent models currently used within HDM-III. The fourth module, socio-economic costs (SEC) enables the prediction of road accident and environmental impacts.

Main Applications of HDM-4

- **Strategic Planning**: to determine medium to long term planning estimates of funding needed for road network development and maintenance.
- **Road Programming**: to determine a schedule of optimum pavement maintenance and /or road improvement projects which can be carried out within specified budget constraints.
- **Project Analysis**: to evaluate one or more road projects or investment options.
- **Research and Policy Studies**: to evaluate the effects of road sector policies on such things as road user costs, energy consumption, vehicle emissions, network asset value.

Advantages of HDM-4 over others

HDM is a user-friendly shell environment for specific customized applications of HDM. It stores the input data efficiently, creates all the required HDM input files, runs the HDM program, collects the results, and presents the results in a practical way. The program is a simple but powerful package for learning and using the major concepts of HDM.

REVIEW OF LITERATURE

Highway development and management is being applied by many highway authorities worldwide and as a technical product, is selling at an ever increasing rate. Highway management being in part following the road building boom of the 1950's and 1960's when countries saw the need to develop their pavement technology and carry out research to refine their maintenance and rehabilitation procedure. A study of the available literature indicated the logic, maintenance strategies; criteria of prioritization etc. used in PMS process vary from country to country due to variations in local traditions in pavement technology, climate, geology and other variations.

Anderson et al (1994) presented his research work on PMS in Australia. It was developed as an in-house software to serve as a decision support tool for the road asset maintenance policy and strategy at the state and district levels. Other states use commercially available software for this purpose. All states use pavement data collection systems. Data gathered includes, but is not limited to roughness, rutting, strength, texture, cracking, skid resistance and seal coat age.

Burger et al (1994) carried out his research in Germany & the design of a new, complete pavement management system is under way. Major components are already operational. Meanwhile, data on road conditions have been collected with high-speed monitoring systems over the national road network, including the Autobahn. The data is assembled according to evenness, skid resistance, and surface damage and subsequently classified via a special grading system. By applying special algorithms, a service value, a structural value, and an overall condition value are being developed. The results of the survey are then presented in lists, route section graphs, and network graphs with different colours indicating where specific target, warning, and threshold values are exceeded. By means of continuous feedback, the information collected is used to improve and adjust the system's components and the plausibility of the output. There is an agreement that for an effective PMS application, repeated automated network monitoring is necessary. To minimize necessary monitoring and evaluation efforts, the use of multifunctional automated monitoring systems is used to collect all necessary data during a single pass.

Medina, A. et al (1999) presented a case study on Geographic Information Systems–Based Pavement Management System. GIS can be a very important element in a decision-support

system by facilitating the preparation, analysis, display, and management of geographical data. In particular, pavement management is a decision process that could benefit from the use of a geographical platform provided by a GIS, because road networks are inherently geographic. Spatial considerations are not only essential in analyzing the different road-related activities, but also can vastly improve the quality of the decision-making process. The combination of RSMS & GIS significantly reduced the effort required to develop the prototype system. It allowed for the development and implementation of a GIS-PMS based on digital data already available to the city. City engineers were very impressed with the prototype system's capabilities. The methodology can easily be used by other cities or towns that have some of the information needed.

Keith B. Madelin (2000) reviewed the development of maintenance management of roads in the United Kingdom since 1936 when the trunk road network was first established. It ranges from the first national study of road maintenance in 1970, includes the introduction of the National Road Maintenance Condition Survey, the development of maintenance codes of practice and concludes with the current development of design, build finance and operate. The involvement of both national and local government is covered and a case study in one county area is described. Author identified three important changes in the approach to road maintenance. The first is the move away from a public sector monopoly in road maintenance towards a mixed economy with an increasing role for the private sector both as manager and contractor. The second is the recognition that the management of maintenance deserves as much attention as new construction. It is now accepted that the management of the road infrastructure will increasingly focus on maintenance and operational management as each country seeks to maximize capacity and minimize the whole life cost of existing assets. The third is the development of maintenance management into asset management with the emphasis on the role of the customer and the recognition that the road network must be managed as a business.

Adelino Ferreira et al (2002) presented a segment-linked optimization model to be used within deterministic pavement management systems. The model is aimed at determining the least-cost maintenance and rehabilitation strategy to be implemented in a road network, considering the applicable technical and budgetary constraints. The evolution of pavements with regard to cracking, rutting, surface disintegration, and longitudinal roughness is estimated with deterministic performance models. The overall quality of pavements is assessed through a modified version of the Present Serviceability Index (PSI). The method developed to solve

the model is based on genetic algorithm principles. The application of the model is illustrated for a case study involving the road network of Coimbra, the third-largest Portuguese city. The results obtained for this case study indicate that the model is a valuable addition to the road engineer's toolbox.

Koji Tsunokawa et al (2003) investigated the relationship between optimal pavement design and maintenance strategy and the level of economic development (LED), using HDM-4. The LED affects the trade-off relationships between initial design and subsequent maintenance, and between road-user costs and agency costs. It was found that pavement strategy should be more economical in developing countries, both for the initial design and the subsequent maintenance. The extent to which pavement should be designed to be sturdier, in order to counteract the insufficient maintenance practices which are so prevalent in developing countries, was also quantified. Based on these results, a formula was derived that predicts the optimal pavement strength as a function of axle loading, LED and level of maintenance insufficiency.

S. Aggarwal et al (2004) described the development of a Pavement Management System (PMS) for an identified National Highway (NH) network in India. This PMS has been necessitated to assist the engineers responsible for maintaining the NH network, as well as the authorities responsible for allocating funds, in making consistent and cost effective decisions, related to maintenance management of the NH network.

Philippe Cheneviere et al (2006) stated that the development of a specific model for the economic assessment of long-life pavements (LLPs) may be required in the future but a first estimation of the potential of LLPs is already possible with the existing models. However, the model does not have the capability to evaluate the environmental costs. The environmental cost module developed as part of an integrated spreadsheet model in the FORMAT project offers some limited scope for the evaluation of environmental costs.

Koji Tsunokawaand et al (2007) discussed three such pitfalls and proposes remedial guidelines for avoiding them using a case study. They pertain to the generation of good maintenance alternatives, defining appropriate analysis periods of HDM-4 runs in relative to planning periods, and obtaining more or less uniform outlays of investment over the analysis period as benchmarks for strategy analyses.

J. Yoo et al (2008) developed multi-dimensional 0–1 knapsack model with alternative-selection and precedence-feasibility constraints. The purpose of the model was to maximize

the total effectiveness of pavement improvement activities in an entire set of selected strategies over a planning period horizon. Dynamic programming and branch and- bound approaches were combined to produce a hybrid algorithm for solving the problem.

W. G. Wong et al (2010) presented a multiple- point excitation model with rear effects (MPEMRE) is deduced and established in the light of the Gray System Theory (GST) method, and the characteristics of model parameters are analyzed. In the analysis of effects of the maintenance and rehabilitation, six typical treatments from current maintenance or rehabilitation alternatives are used and the model parameters are determined, combined with the analysis of the treatment effects.

Adelino Ferreira et al (2011) compared different pavement performance models (PPMs) from around the world and recommends one for use in the Portuguese pavement management systems (PMS). The paper is divided into three complementary sections. The first section describes several PPMs used around the world.

Diana Jorge et al (2012) presented a new maintenance optimization system (MOS), called GENEPAV-HDM4, which was developed to integrate the pavement management system (PMS) of the municipality of Viseu (Portugal). At the same time, it was also developed for possible application to other existing PMS that need an upgrade due to recent Portuguese legislation. This is the case of the PMS used by the main Portuguese concessionaire Estradas de Portugal, SA.

Florian Gschosser et al (2012) stated that for all analyzed processes, the material production has the biggest impact on the values of the three analyzed environmental indicators, i.e. this is the most influential life-cycle phase of a road pavement.

Susana Meneses et al (2013) presented the development and implementation of a Multi-Objective Decision-Aid Tool (MODAT) tested with data from the Estradas de Portugal's Pavement Management System. The MODAT uses a multi-objective deterministic section-linked optimization model with different possible goals: minimization of agency costs, minimization of user costs, maximization of the residual value of pavements, etc. The MODAT also uses the deterministic pavement performance model used in the AASHTO flexible pavement design method.

Mohammad Jamal Khattak et al (2013) evaluated and updated the performance models for different pavement types and highway classifications as used by LADOTD. This paper discusses the development of index-based rigid and composite pavement models.

Andrzej Pozarycki (2014) discussed potential practical applications of plate bearing test numerical simulation based on Falling Weight Deflectometer (FWD) deflection data, and theoretical model based on flexible pavement. It was proven that including a pavement model with stress dependency, the simulated second load-displacement curves meet reliably plate bearing in-situ test conditions for different layers of either subgrade or base courses of road pavement.

Swapan Kumar Bagui et al (2015) discussed a case study where a level 1 calibration has been carried out for a State Highway in Uttar Pradesh, India. The climatic condition of the site is under humid, hot and high monthly precipitation throughout the year. Two methods have been proposed to find out the calibration factors. The process for the level 1-calibration factors have been found out using HDM-4 level 1 calibration method using model and verified using HDM-4 software. The proposed methodologies may be used for the determination of calibration factor to use economic analysis for feasibility study and budget purposes.

Hamad Al-Ajami et al (2015) presented comprehensive review for the pavement maintenance management system (PMMS), especially in Riyadh city, where pavement management maintenance system is considered as a systemic method that aids in assessing the pavement performance and condition of existing and future pavement.

Shah Yogesh et al (2016) described the adaptation of the World Bank's highway development and management model HDM-4 at the strategic level. The analysis was carried out to maximize the net present value (NPV) and minimize the costs to achieve a desirable target international roughness index (IRI). The analysis results presented the need for the optimal capital and recurrent maintenance required to maintain the urban road network in serviceable condition.

Sanjay Deori et al (2016) discussed the calibration of distress models of internationally recognized/accepted World Bank’s HDM-4 system tool for selected pavement sections of Indian high-speed road corridor network having modified bituminous mix as surface course for Indian climatic conditions. The HDM-4 pavement deterioration models for flexible pavements have been calibrated based on the available time series data collected from the pavement test

sections and could also be used for predicting the road conditions for modified bituminous road surfacing for future maintenance planning and strategies.

Marwan Hafez et al (2017) concluded that Low Volume Roads (LVRs) have different traffic volume ranges among states. Transportation agencies are encouraged to consider appropriate traffic volumes for LVRs depending on the traffic volume distribution in their jurisdictions and Pavement condition data should be collected at the network level. PCI, IRI and rut depths are the most common condition data as measured indices, whereas Pavement Surface Evaluation Rating (PASER) is the most common visual inspection survey.

Misbah U. Khan et al (2017) presented scientifically deriving optimum pavement maintenance strategies using TMR as an example. The well-known HDM-4 model has been used to obtain optimum standards and strategies for the whole road network with the optimization objective of 'minimizing agency cost and maximizing performance'. The current approach uses economic optimization to get the best standard and strategy for a road group, which is useful for the pavement engineers and asset management practitioners.

Tanuj Chopra et al (2017) presented the use of HDM-4 model for the computation of optimum Maintenance and Rehabilitation (M&R) strategy for each road section and comparative study of scheduled and condition responsive M&R strategies. The results of present study will be useful for gaining better support for decision-makers for adequate and timely fund allocations for preservation of the urban road network.

Abdelilah Bannour et al (2017) developed the calibration factors for predicting the deterioration (structural cracking, raveling, potholes and their resultant roughness) of roads in Morocco. The careful choice of such maintenance work planning is based on the result of these models. The used method is based on a statistical analysis using equations implemented in HDM-4 models. The calibration process of the pavement behavior was performed by a linear regression between the predicted values and observed values. Thereafter, the calibration factors for the initiation and the propagation of each damage in the models were determined.

Joao Santos et al (2017) presented the development of an Adaptive Hybrid Genetic Algorithm (AHGA) intended to help decision makers in the field of pavement management tackle the optimization problem consisting of minimizing the life cycle M&R costs of a given pavement section throughout its PAP, while keeping the pavement condition above a predefined threshold

value, meeting technical constraints and considering deterministic and non-linear pavement performance prediction models (PPPM).

Joao Santos et al (2018) developed a multi-objective optimization framework that hosts a comprehensive and integrated pavement life cycle costs–life cycle assessment model that covers the pavement's whole life cycle, from the extraction and production of materials to construction and maintenance, transportation of materials, work-zone traffic management, usage and end-of-life. The sustainability of pavement systems requires the development of optimization based decision support system (DSS) for pavement management with the capability to identify optimally sustainable pavement maintenance and rehabilitations (M&R) strategies.

Dan Chong et al (2018) discussed the impacts of management decisions are examined in three dimensions, including life-cycle cost (LCC), energy consumption, and greenhouse gas (GHG) emissions. Quantitative models to predict the three dimensions are developed from mechanistic-empirical pavement analysis results. Author(s) also concluded that the optimum pavement thickness decreases with the decrease of traffic level, while the optimum IRI trigger value does not vary greatly with traffic levels. Hence, the agency may consider adopting a uniform IRI trigger value.

Antonio Pantuso et al (2019) presents a methodology for analyzing the collected pavement data for the implementation of a network level pavement management program in Kazakhstan. The use of the Pavement Condition Rating (PCR), to give an overall score of the pavement functional condition, would be valid for deciding pavement needs at the network level, and it can be used as a first screening tool for identifying the most suitable pavement maintenance treatment in pavement sections.

Strategy in India

The concept of pavement management system (PMS) was introduce in India in mid-eighties. Since then, no. of studies had been conducted in the interest to develop PMS. In 1991 very first time computerized pavement management system was introduced in state of Tamilnadu & Andhra pardesh. After that in the state of Karnataka and Uttar paresh had taken up this assignment to develop computerized pavement management system.

Research Gap

The existing research primarily focuses on developing optimization-based techniques for either maximizing performance of roadway segments and/or minimizing total costs subject to, generally speaking, a financial and minimum pavement condition constraint; defining performance is difficult to do as its definition is multifarious. An important trend that emerges is that the dimensionality of the context has increased gradually over time, starting with earlier top-down approaches that allocate resources to groups of segments and gradually moving towards facility specific models. Additionally, although the size of the network has continued to grow, the rehabilitation types are still fairly ambiguous and the time-horizon continues to leans towards the short/medium-term. The pavement management system development was done to provide a rational framework for organizing and coordinating existing knowledge on pavement and for projecting future research needs. That purpose is still valid today. Unfortunately, because of the many details involved in pavement design, construction, and maintenance, and the availability of a large amount of technology, agencies often find themselves working at cross purpose, internally, without proper coordination on pavement research. Some of the agencies and researchers had developed the system but it was concerned and liable to localized only. None of the system developed earlier was applicable to all over the world with the modification & calibration according to the concerned region. So there is much need of time to developed pavement management system with application of wide aspects. The research trend in the field of pavement management could be grouped into three main areas. The first one is related to pavement management systems, which attracted the greatest attention, especially optimization processes with various objectives and life cycle cost analysis. The second group is about pavement performance modeling, where calibration of mechanical empirical models was largely developed. Lastly, data collection had also occupied several papers, mainly about cracking classification. Sustainability aspects in pavement management became an emergent issue.

Problem formulation

Falling to carry out pavement maintenance in a systematic manner not only risk part of the very significant resources spent on pavement construction, but far more resources need to be spent to restore the pavement to an acceptable serviceable condition. So there is need of developing a scientific approach towards determining the maintenance and rehabilitation strategies for pavements conditions. These tools are essential for assessing the funds,

evaluation the alternatives strategies for M&R. In such situations, developed pavement management system would fulfil the objectives of this study. This task will accomplished by HDM-4 software. The development of HDM-4 has been primarily sponsored by Asian Development Bank (ADB), Department for International Development (DFID) UK, Swedish National Road Administration (SNRA), The World Bank, on the recommendation of the General Secretariat of World Road Association Council-PIARC. Pavement maintenance is a continuous activity because of the deterioration with time. In addition, the policy framework continues to develop because of increasing traffic volumes, developments in materials and techniques available to engineers, and climate change. For this reason, the maintenance guidelines/ethics will be subject to periodic reviews to ensure that authorities have access to best practices across the range of pavement maintenance activities.

Research Objectives

The aim of this study is to develop a pavement maintenance management system (PMMS) for identified highway network situated in Punjab, Haryana & Himachal Pradesh, which shall have following objectives.

- To predict the future condition of the pavement of different sections of the road network.
- To propose appropriate maintenance strategy to be adopted during the selected period of time to maintain road conditions at an acceptable level.
- To forecast budget estimates to meet the maintenance requirement of the road network.
- To suggest alternative maintenance strategy to be adopted in case of non-availability of full budget.

Contribution and need of the proposed Research

The research is to help to development of Pavement Maintenance Management System for Highway Network in India. This requires development of particular pavement segments and prioritization of maintenance activities in the event of a constrained budget.

Methodology

1. **Define the Roadway Network and Collect Inventory Data** -The first step in designing a pavement management process is to define the roadway network. A roadway network is comprised of an inventory of the physical characteristics of the roadways being managed by the agency. The inventories are typically built by dividing the network roadways into manageable segments.
2. **Collection of Pavement Condition Data-** Pavement condition data are a major factor in any data-driven, decision-making pavement management process. Within the pavement management process, the condition data can be used to help identify current maintenance and rehabilitation needs, to predict future needs, and to assess the overall impact on the network. Therefore, the type of condition data required and the level of detail depends on the agency and the pavement management process used.
3. **Use Pavement Maintenance Management Tool (HDM-4) -** This international software tool provides a platform to store the pavement maintenance management information and to perform different types of analysis. This tool shall be calibrated to suit to the requirements of the study area road network.
4. **Report Results -** The reporting of project results is the fourth step in the implementation process, in which the results of data analysis are presented. The findings can be reported using different methods to highlight important factors, which will assist decision makers in making various decisions.
5. **Predict Pavement Section Condition -** With current pavement condition assessed and with the analysis information needed to predict the future condition of a pavement section through Pavement maintenance management system.
6. **Predict budget requirements for maintenance management of road network**- After knowing the required maintenance strategies for road network, approximate budget will be automatically calculated and presented.
7. **Recommendations -** The final step in designing the pavement maintenance management system is to select appropriate recommendations for the roadway network. The selection of treatments is based on the defined maintenance and rehabilitation strategy, which is created by selecting trigger values to identify segments needing repair.

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Place of Work

Research work will be carried out at Department of Civil Engineering, Giani Zail Singh Campus College of Engineering & Technology Maharaja Ranjit Singh Punjab Technical University, Bathinda, Punjab, India.

Resources (Hardware/Software) required & availability status

To carry out the proposed research work following item/software(s) is required.

- Highway Development and Maintenance-4 (HDM-4) version 2.0 software sponsored by World Bank. HDM-4 version 2.0 has been updated to use the latest version of this database to ensure the latest developments and enhancements are available, as well as continued support and backup from the suppliers is accessible.